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Effects of CP-Violation in Neutralino Scattering and Annihilation

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We show that in some regions of supersymmetric parameter space, CP violating effects that mix the CP-even and CP-odd Higgs bosons can enhance the neutralino annihilation rate, and hence the indirect detection rate of neutralino dark matter, by factors of 10^6. The same CP violating effects can reduce the neutralino scattering rate off nucleons, and hence the direct detection rate of neutralino dark matter, by factors of 10^{-7}. We study the dependence of these effects on the phase of the trilinear coupling A, and find cases in the region being probed by dark matter searches which are experimentally excluded when CP is conserved but are allowed when CP is violated.

The neutralino elastic scattering cross section (in pb) is plotted in fig. 1 as a function of neutralino mass (in GeV) for $\sim 10^6$ values in SUSY parameter space. The upper panel is for the case of CP violation via $\mathrm{Im}(A) \neq 0$ while the lower panel is for the case of no CP violation. In the upper panel, it is the maximally enhanced cross section (as a function of $\arg(A)$) that is plotted. The dark points refer to those values of parameter space which have the maximum value of the cross section for nonzero $\mathrm{Im}(A)$ and which are experimentally excluded at zero $\mathrm{Im}(A)$. The grey region refer to those values of parameter space which are enhanced when CP violation is included and which are allowed also at zero $\mathrm{Im}(A)$. The light grey empty squares refer to those values of parameter space which have no enhancement when CP violation is included. The solid lines indicate the current experimental bounds placed by DAMA and CDMS; the dashed lines indicate the future reach of the CDMS (Soudan), GENIUS, and CRESST proposals.

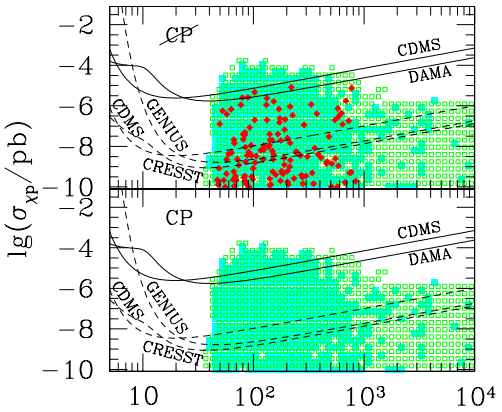

Figure 1.

In fig. 2 we show the enhancement and suppression factors of the elastic scattering cross section for the case of CP violating $\arg(A)$. The plot shows the ratios $R_{\max} = \sigma^{\max}/\max[\sigma(0), \sigma(\pi)] > 1$ and $R_{\min} = \sigma^{\min}/\min[\sigma(0), \sigma(\pi)]$ as a function of the values ϕ_A of the phase of A where the maximum/minimum occur Here $\sigma^{\max}$ ($\sigma^{\min}$) is the enhanced (suppressed) scattering cross section and the superscript max (min) indicates the maximal enhancement (suppression) as one goes through the phase of A. The denominator of the ratio $R_{\max}$ ($R_{\min}$) chooses the larger (smaller) value of the scattering cross section without CP violation, i.e., for phase $= 0$ or phase $= \pi$.

Fig. 3 shows the enhancement and suppression factors of the neutralino annihilation cross section times relative velocity σv (at $v = 0$). The ratios $R^{\mathrm{ann}}_{\max}$ and $R^{\mathrm{ann}}_{\min}$ are defined similarly to $R_{\max}$ and

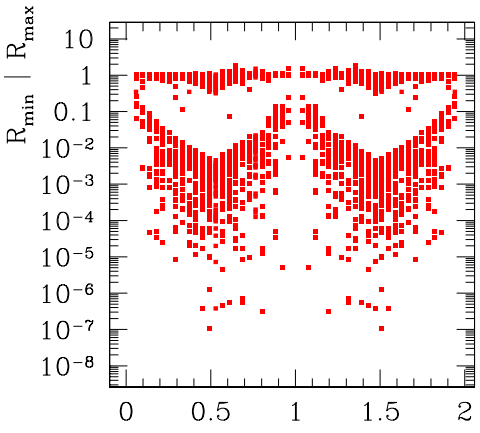

Figure 2.

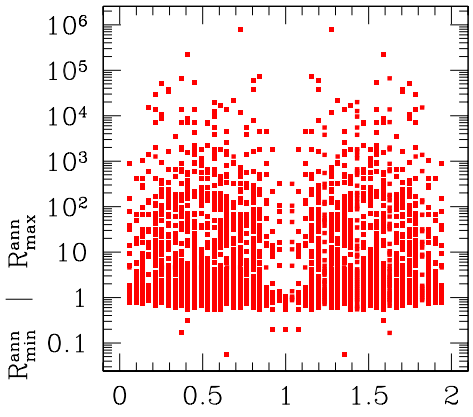

Figure 3.

$R_{\rm min}$ but with σv replacing the scattering cross section σ.

Finally, in figs. 4 and 5 we show two examples of the behavior of the scattering and annihilation cross sections with the phase of A. The four panels from top to bottom display the following: the scattering cross section $\sigma_{\chi p}$ in pb, the annihilation cross section σv in cm^3/s, the branching ratio BR$(b \to s\gamma) \times 10^4$, and the lightest Higgs boson mass m_{h_1} in GeV as a function of the phase ϕ_A of A. CP conserving phases are $\phi_A = 0, \pi$ while all other values are CP violating. In the third and fourth panels we hatch the regions currently ruled out by accelerator experiments. In all four panels we denote the part of the curves that is experimentally allowed by thickened solid lines, and the part that is experimentally ruled out by thinner solid lines. In this figure, the possible phases are bound by the limit on the $b \to s\gamma$ branching ratio. In the allowed regions, the scattering cross section at CP-violating phases is suppressed, while the annihilation cross section is enhanced. The latter takes its maximum allowed value when the $b \to s\gamma$ limit is reached. In the case plotted in fig. 4, both CP conserving cases are experimentally excluded while some CP violating cases are allowed. The scattering cross section is of the order of 10^{-6} pb, and lies in the region being probed by direct detection experiments. The annihilation cross section peaks at $\phi_A = 3\pi/4$; notice that this value is not the point of maximal CP violation $\phi_A = \pi/2$.

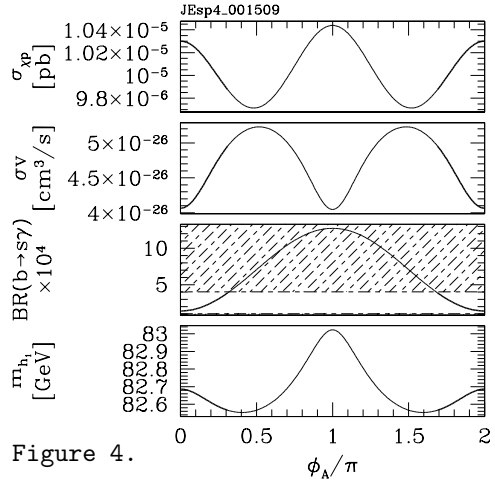

Figure 4.

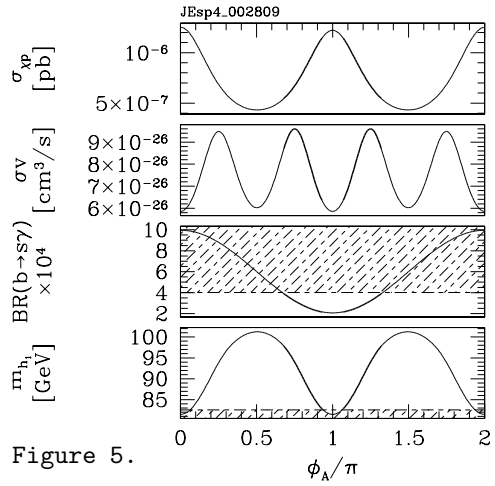

Figure 5.

A detailed presentation and references can be found in Gondolo and Freese, hep-ph/9908390.